Seat No: _____

NED UNIVERSITY OF ENGINEERING & TECHNOLOGY
MASTER OF ENGINEERING (MECHANICAL)
SPRING SEMESTER EXAMINATIONS 2023

Time: 3 Hours AZHAR KHAN Dated:15-AUG-2023
Max.Marks:60

MICRO-& NANO-ELECTROMECHANICAL SYSTEMS - MC-539

Instructions: *Attempt all questions*

Q1: MCQs/Do as directed: **(20 Marks)**

1) For a fixed plate parallel plate capacitive actuator with one end connected through a spring, the applied electrical force must be greater than the mechanical force to actuate it to the desired position (True, False).
2) Shape memory alloy are semiconductor materials (True, False).
3) Single Carbon Nano Tube (CNTs) are preferred for large assemblies. (True, False)
4) Laser method is the least expensive method for production of CNTs. (True, False)
5) The main difference is, the Graphene is a single thin layer 2D film, while the carbon nanotubes in a thin film rolled like a 3D tube or cylinder (True, False)
6) Graphene can be formed by thermal deposition of silicon carbide. (True, False)
7) MEMS microphones can perform _____
   a. Digitization,
   b. beam forming,
   c. noise cancellation
   d. All of the above
8) At the static position, the mechanical force restraining the movement of an electrostatic actuator is always _____ to the electrical force.
   a. Equal and in same direction
   b. Equal but in opposite direction
   c. Greater and in same direction
   d. Greater but in opposite direction
9) Electrostatic actuators rely on differential _____ (voltage, current).
10) For high response speed, _____ (thermal, electrostatic, magnetic) actuators are preferred.
11) Graphene is far _____ (inferior, superior) to carbon nanotubes.
12) Chemical vaporization method provides a yield up to _____ (40, 70, 100) %.
13) In arc-discharge method, the source of Carbon is _____ (graphite, hydrocarbon).
14) In Laser and Arc discharge method of CNT production, huge amount of energy is required.
15) Electrostatic sensing & actuation methods are suitable for _____(low, high) frequency applications.
16) Carbon Nano-tubes (CNTs) have _____ (high, low) mechanical strength and high _____ (thermal, electrical, both thermal and electrical) conductivity.
17) _____ (Graphene, Carbon Nano-tube, hydrocarbon) is a single two-dimensional layer of carbon atoms bound in a hexagonal lattice structure.
18) Nano-submarine is used to deliver drug to tissues, through blood stream, is powered by _____.
19) Shape memory alloys can only retain their shape back if _____ (heated, magnetized).
20) A microfluidics system for chemical and biological diagnosis is known as _____
   a. Micro total analysis system
   b. Lab-on-chip system
   c. Both a and b
   d. None of the above

Q2. *Describe two key advantages of electrostatic actuators and sensors.* **(1.0)**

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A circular diaphragm (shown in Fig.1) is to be designed to produce a micro pressure sensor, the diaphragm has a diameter of 1 mm and is rigidly fixed to a silicon support around its entire periphery. The silicon diaphragm material (σ_y =7000 MPa, E=190000MPa, Υ=0.25) must withstand an external pressure of 30 MPa.

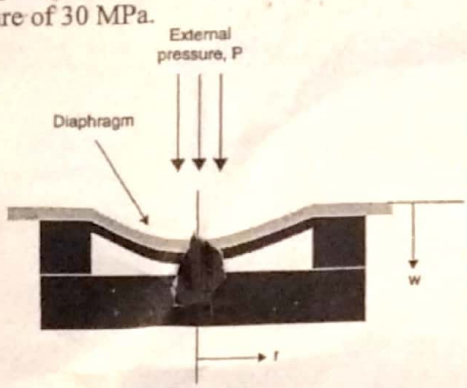

Fig. 1

i. Calculate the minimum diaphragm thickness to avoid yielding. (2.0)
ii. What is the minimum deflection of the diaphragm. (1.0)
iii. What would be the maximum external pressure on the diaphragm if the thickness calculated in (i) is doubled? Comment on results. (2.0)

An Ohmic heater is located in the middle of a suspended fixed-fixed cantilever as shown in Fig.2. The beam is made of silicon nitride and the metal leads are made of Aluminum.

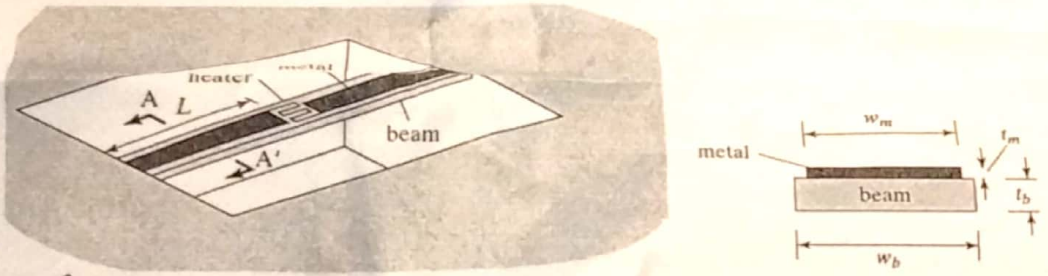

Fig. 2

i. Find the numerical value of the thermal resistance experienced by the heater. Assume the width of the beam is 10 µm with L= 100 µm. and the thickness of both aluminum and silicon nitride is 5.0 µm each. **(2.0)**
ii. What would be the steady temperature if the input power to the heater is 10 mW. Assume that the silicon bulk stays at room temperature (i.e. 25°C) and the thermal conductivity of Aluminum and silicon nitride is 240 and 5 W/mK, respectively. **(2.0)**

Q3.

The intrinsic carrier concentration of Silicon at room temperature is 1.5×10^{15} per cm^3. A Silicon piece is doped with Phosphorus to a concentration of 2×10^{18} per cm^3. The mobility of electron and holes is the Silicon is approximately 1500 cm^2/V-s and 500 cm^2/V-s, respectively.

i. Find the conductivity of the doped bulk Silicon. (3.0)
ii. Find the resistance of doped bulk Silicon, if the length and area of cross section of Silicon is 10 µcm and 2.0 µcm^2, respectively. (1.0)
iii. What would be the power requirement if the bias current is 2 mA? (1.0)

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b. Calculate the net spring constant of the structure shown in Fig.3 with K_1=K_2=10 N/cm. (2.0)

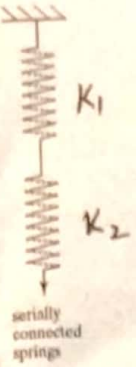


Fig. 3

c. Draw the structure of Graphene. (1.0)

d. CNTs are potential candidate for (i) solar cells, (ii) Hydrogen storage. Justify the statement. (2.0)

Q4 a. Explain the working of electrostatic micromotor shown in Fig. 4. (2.0)

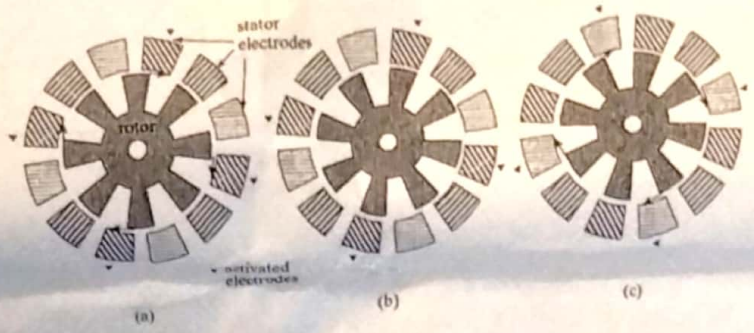
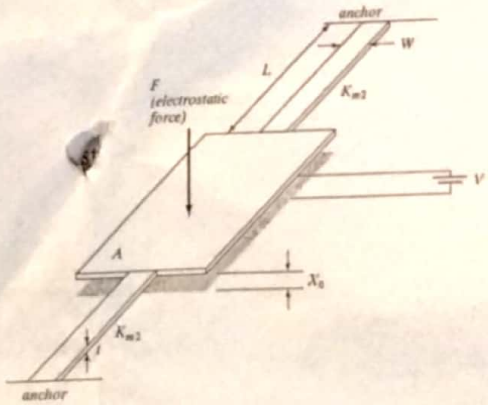


Fig. 4

b. A parallel plate capacitor is suspended by two fixed-guided cantilever beams, each with length, width and thickness being 800 μm, 20 μm and 2 μm. The gap between the plates is 4 μm and the area of plates is 500 μm x 500 μm. The material is polysilicon with a Young's modulus of 120 GPa. Find the total force constant for the structure shown in Fig. 5 (3.0)



0.0375

Fig. 5

clarificat

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What is the typical order of magnitude (value) of input voltage and output torque for the micromotor shown in Fig. 4? (1.0)

An air-gap fixed parallel planar plate capacitor has distance of 200 μm between two plates with a voltage of 10 Volts and area of plates is 500x500 μm^2

i. Calculate the capacitance and electric force when air is present between the plates. (2.0)
ii. Calculate the capacitance when half of the area is filled with water between the plates. (1.0)
iii. Also calculate the electric force in (ii). (1.0)

(Assume relative permittivity of water is 100 times of air and absolute permittivity be 8.85×10^{-12})

Q6

a. Describe the functioning of at least ONE of the following MEMS applications shown in Fig. 6 (3.0)

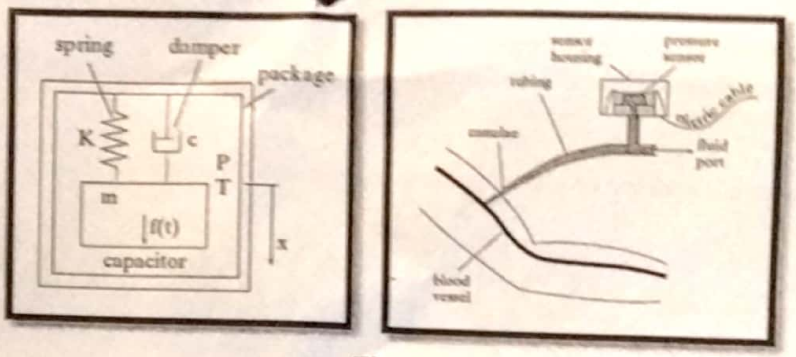
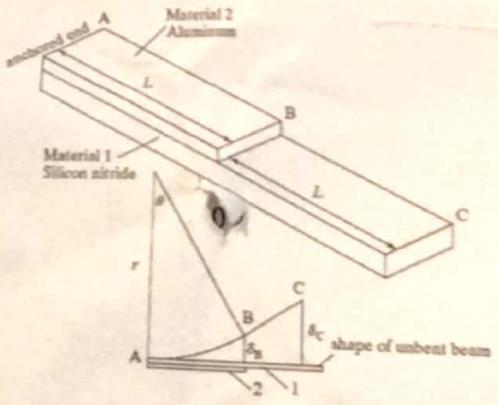


Fig. 6

b. In Fig. 7, a bimetallic cantilever beam is shown with two layers of different length. The top layer is of Aluminum (Thickness= 0.5 μm, E_2=70 GPa, α_2=25 ppm/°C) and bottom layer is of Silicon Nitride (Thickness= 1 μm, E_1=250 GPa, α_1=3 ppm/°C). The width of both layers is 20 μm. The length of segment between Point A and B is 100 μm, so is the length of segment from Point B to C.

i. Find the radius of curvature (r) of the cantilever beam when the beam is uniformly heated to 20 °C above the room temperature. (2.0)
ii. Calculate the amount of vertical displacement at the free end of the bean. (1.0)



$$\delta_C = \delta_B + L\sin(\theta)$$

$$\delta_B = r - r\cos(\theta)$$

Fig. 7

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3. Describe the major benefits (at least three) of a microfluidics system in comparison with bench-top diagnosis system. (3.0)

4. Name at least three methods of controlled movement of fluid on a chip. (1.0)

Note: You may need to use:

$\sigma_y = (3YPr^2)/8t^2$, deflection, $w = 3P(1-Y^2)r^4/(16Et^3)$

$$\rho = \frac{1}{\sigma} = \frac{1}{\sigma_n + \sigma_p} \approx \frac{1}{q(\mu_n n + \mu_p p)}, \qquad R = \rho\frac{l}{wt},$$

$$n_0 p_0 = n_i^2$$

$$F_{electric} = \frac{1}{2}\frac{\varepsilon A}{d^2}V^2 = \frac{1}{2}\frac{CV^2}{d}$$

$$\frac{1}{r} = \frac{6w_1w_2E_1E_2t_1t_2(t_1 + t_2)(\alpha_1 - \alpha_2)\Delta T}{(w_1E_1t_1^2)^2 + (w_2E_2t_2^2)^2 + 2w_1w_2E_1E_2t_1t_2(2t_1^2 + 3t_1t_2 + 2t_2^2)}$$

$$\theta = l/r, \quad R = \rho\frac{l}{A}, \quad K_m = \frac{F}{d}, \quad d = \frac{Fl^3}{12EI}, \quad I = \frac{wt^3}{12}, \quad I = \frac{\pi R^4}{4}.$$

Good Luck